Army Research Laboratory

The Development of a Virtual McKenna Military Operations in Urban Terrain (MOUT) Site for Command, Control, Communication, Computing, Intelligence, Surveillance, and Reconnaissance (C4ISR) Studies

by David R. Scribner and Patrick H. Wiley

ARL-TR-4139 **June 2007**

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT

Virtual environments are being used more frequently by researchers to collect human performance data before and in lieu of costly field experiments. The McKenna Military Operations in Urban Terrain (MOUT) site at Fort Benning, Georgia, is used for training and experimentation with Soldiers using new equipment and tactics. A low-cost reusable virtual representation of the McKenna MOUT site was built with the use of a popular first-person shooter PC game, Tom Clancy's Rainbow Six 3: Raven Shield[1], which focuses on small unit tactics in complex urban environments. The focus of this report is the process of building a new, cost-efficient, high-fidelity custom environment complete with accurate representations of buildings, terrain, vegetation, and combinations of enemy units and objectives to model real training situations.

[1]Raven Shield is a trademark of Red Storm Entertainment.

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1. Introduction

This reports outlines the process undertaken to provide a virtual McKenna military operations in urban terrain (MOUT) site (VMMS) at Fort Benning, Georgia, for use as a command, control, communication, computing, intelligence, surveillance, and reconnaissance (C4ISR) simulation tool to collect Soldier-in-the-loop data to estimate individual, fire team, or squad performance and decision-making capabilities with the use of advanced sensors. This project began in June 2002 at the Dismounted Warrior Branch of the U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate (HRED).

HRED's Dismounted Warrior Branch has been tasked several times to create Soldier performance models in IMPRINT (improved performance research integration tool), a stochastic system that aids in human workload and error prediction. It is often the case that performance modelers lack equipment upon which to base time and error rate estimates for behaviors of Soldiers with new equipment. The environments that Soldiers will be exposed to (such as MOUT) are not readily available either.

There are several basic tasks that all dismounted Soldiers must perform, often in a multi-task environment. These behaviors are listed in figure 1 with the associated simulator system. The dismounted infantry survivability and lethality test bed (DISALT) is a high fidelity shooting simulator used by ARL's HRED. The figure shows that each simulator environment has some elements of exclusivity and overlap. The VMMS lacks the "shooting" behavior aspect, yet allows some movement, orientation, and navigation tasks to be performed under the general "MOVE" task.

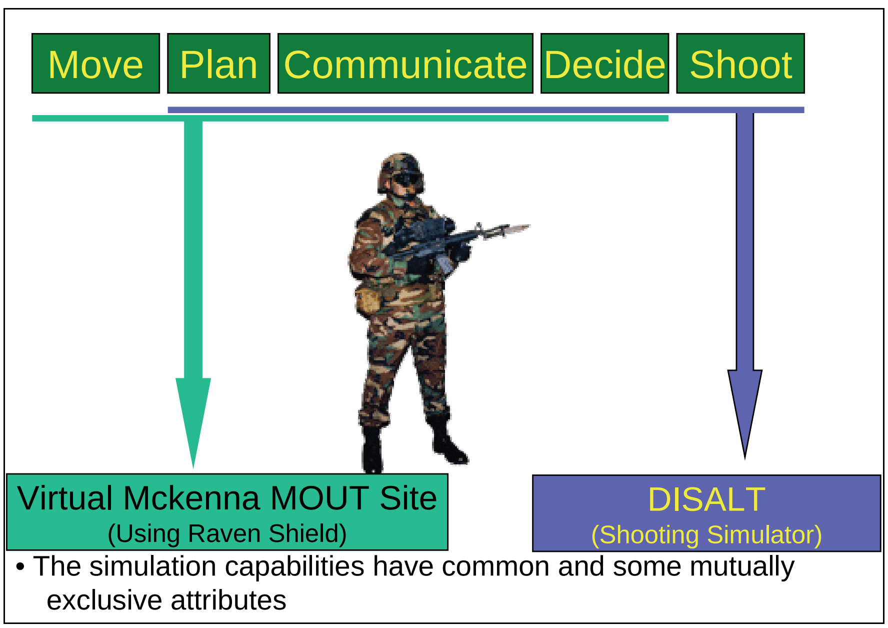

Figure 1. Basic Soldier tasks and simulator environmental capabilities.

2. Why Build the Virtual McKenna Site?

Creating a virtual McKenna site filled several needs:

1. To establish a highly realistic and detailed virtual world in which to perform individual and team-based research for situational awareness (SA) where various sensors and communications variables could be examined,

2. To support a SA questionnaire validation study being performed at the Fort Benning field element of ARL's HRED,

3. To allow research at ARL that would allow human performance modelers to collect data where currently there are voids in human performance data,

4. To perform research for the science and technology objective (STO) for situational understanding (SU) as an enabler for unit of action (UoA) maneuver team Soldiers.

In addition to the obvious benefits of having such an environment, the Fort Benning field element, with this VMMS, was allowed the "virtual" experimentation of concepts and ideas before spending as much as $50,000 a day in using the actual McKenna MOUT site, thus saving the finely tuned concepts for the high-payoff focus of research. The lack of mock-ups leaves the possibilities of virtual testing a good choice for human factors engineers and human performance researchers. Data collected from such a study could be used in a validation study of live performance as well.

In support of the SU STO, the Army vision states that U.S. forces must have the ability to generate overmatching combat power by employing the mix of maneuver, firepower, protection, and leadership. All this is enabled by dominant SU. The operational requirements document (14 April 2003) for the Future Combat Systems (FCS) states that the UoA is the central building block for the future force, which will use the power of information and human potential and combine the advantage of light and mechanized forces.

The STO for SU as an enabler for UoA maneuver team Soldiers has stated that the purpose of the SU STO is to

> Develop, demonstrate, and transition UoA Soldier information system interface solutions that address differences in the way Soldiers gain situational understanding and enable planning and acting within the adversary's decision cycle.

The products being sought are interface design solutions for UoA maneuver team information systems that enhance SU and decision cycle performance.

The display of information to a fire team leader can affect his or her immediate perception and SA of the surroundings that would affect decision making and projection of what is happening in his or her combat space. The C4ISR research will use the same virtual environment to answer questions, based on the availability of a platoon-level unmanned aerial vehicle (UAV) providing sensor feed, the use of a common operational picture (COP), and the use of another Soldier whose function is to examine all sensor information and translate that to a fire team leader who may be too busy to attend to all visual displays while on the ground and performing a mission.

Three basic technological areas will affect the quality of how a Soldier in the UoA will do his or her job: 1) improvements in weapons technology, such as the objective individual combat weapon (a new air-bursting munition capable of defeating enemy behind cover), 2) the increasing probability that future operations will be in MOUT scenarios, and 3) the advancement of C4I systems. The VMMS development primarily addresses the MOUT and C4ISR aspects of the encroaching technologies and environments.

The Project Manager (PM) Soldier (Land Warrior) and PM Future Force Warrior have made significant progress in bringing information in a meaningful way to the Soldier; however, the workload and attentional demands of using such a system in single-task, dual-task, or multi-task environments have not been assessed to date. If these systems are not designed with the target population's capabilities, limits, needs, and environments in mind, this alone or in combination with a new highly technical weapon systems of the future may bring failure in terms of Soldier information processing ability, Soldier task performance, and Soldier lethality. Emerging technological advances in certain areas will also affect the quality of the job.

The capability of these systems will provide 1) enhanced communication (squad radio and intra-squad communications), 2) enhanced navigation features, 3) weapon-sensor connectivity (to allow viewing of targets indirectly), and 4) other data access such as a COP display that will provide 100% friendly and 8% to 15% enemy unit locations (FCS ORD, April 2003).

These information-bearing systems will change the face of the infantryman's job, but many questions remain unanswered about these systems.

3. Capabilities of Raven Shield

Numerous commercial off-the-shelf gaming technologies were examined for this effort. Several candidates were reviewed to assess suitability for the research needs of the organization. The particular software selected, a first-person shooter, was Tom Clancy's Rainbow Six 3: Raven Shield. It was selected because of its balance of modern militaristic realism including weapons, environments, and clothing that was selectable. It had very high fidelity graphics and lighting, allowed multi-player setup over internet or local area network, and contained an editor based on the highly popularized Unreal[1] Tournament 2003. This Unreal Editor allows the user, with little to no computer-aided design background, to build a new gaming environment or "map" as it is

[1] Unreal is a registered trademark of Atari, Inc.

named on the popular fan-based internet sites. This included the generation of terrain, vegetation, buildings, skycover, interior and exterior lighting levels, and the placement of enemy artificial intelligence ("AI") units (or computer-controlled enemy) that can be configured with various weapons, clothing, and behaviors. In summary, the following lists the general qualities available in Raven Shield that were sought:

- **Various Terrains and Scenarios –** Have in-house capability to generate any three-dimensional (3-D) terrain type (urban, rural) and target scenarios with various lighting and weather conditions.
- **Squad-Level (eight nodes) Performance –** The simulation allows as many as eight Soldiers to link and perform a mission in a virtual world as a real-time team.
- **Various C4I Modes –** Various types of communication modes can be used to allow the relay of information across, up, or down echelons.
- **Surveillance and Reconnaissance Modes –** Various ground and airborne sensors may be "simulated" to show advance sensor use on the battlefield.
- **Opposing Force (OPFOR) –** This may be set up as computer AI (as many as 35 or just over platoon strength) or humans (as many as eight nodes or just under squad strength) for scripted behaviors.

A large number of capabilities with Raven Shield can be viewed as potential C4ISR variables (independent) to be used. These are listed in table 1. Dependent variables that could be collected for data are also included.

Table 1. Potential raven shield variables.

Independent Variables	**Data Source**
Voice Communication, Free Format	(Battlecom (PC) or Motorola Radios, Voice)
Pre-Canned Voice Messages	(Raven Shield)
Text Messaging	(Raven Shield)
Voice Activation of Sub-systems	(Shoot 1.6)
Bone-Conducting Communication system	HRED-available hardware
Radar Representation of Friendlies	(Raven Shield)
Map Position of Friendlies	(Raven Shield)
In-Simulation Cooperative Draw Tool	(Raven Shield)
UAV or Unmanned Ground Vehicle (UGV) Sensor View	(Raven Shield, added computer node)
See-Through Walls Sensor	(Raven Shield)
Thermal Sensor	(Raven Shield)
Dependent Variables	
Mission Time	(Raven Shield)
Mission Success or Failure	(Raven Shield)
Friendlies Killed	(Raven Shield)
Enemy Killed	(Raven Shield)
SA Questionnaire Response Ratings	Questionnaire, SA Study@Benning
Mode Effectiveness Ratings	Questionnaire
Workload Ratings of Various Modes	Subjective workload assessment technique or National Aeronautics and Space Administration task load index

This effort was presented in concept, including the potential for data collection, to many visitors to ARL including the Fort Benning field element chief, MicroAnalysis and Design, and several ARL branches including the Cognitive Sciences Branch. The primary focus of these briefings was to relate the potential strength of Raven Shield for mimicking UAV, UGV, and various communication modes. One highly interesting communication mode in Raven Shield is the "Draw Tool". This is essentially a static, top-down aerial view of the area of operations that can be drawn upon in a cooperative "whiteboard" mode. This allows players to view a common map of the area while a quick drawing is produced by the team leader. It has been found in informal piloting of this system that much tactical intent and information can be relayed in a short amount of time for the next tactical decision or action.

4. Building the McKenna MOUT Site

The first step in building the VMMS was to gather as much information about it as possible. A satellite photo (see figure 2) of Fort Benning was retrieved from open source data at TerraServer.com and the U.S. Geological Services web sites. Photographs of McKenna and interior building floor plans were collected from the internet and from Fort Benning personnel. Additionally, a MultiGen-paradigm OpenFlight format model of McKenna was obtained from ARL's Computational and Information Sciences Directorate. This included terrain and buildings. The buildings could not be translated into a usable format for the Unreal Editor. However, the elevation data from the terrain were usable and are discussed later in this report.

The McKenna MOUT site is approximately 200 meters square and includes 15 European-styled buildings set up as a village. There are a church, small houses, domestic residences and some office-style buildings. There is an open field to the north, approaching a dirt air strip. There are trees to the east, south, and most of the west. There are several support areas that are fenced and a subterranean sewer system that is not often used.

Concrete roads run through the middle of the village going north and south, and several dirt and stone trails encircle the perimeter of the village. Figure 3 shows the McKenna MOUT site.

The building process began with several tutorials on the Raven Shield version of the Unreal Editor and "how-to" documents from various fan-based web sites. There are tutorials for editing ranging from how to create a first environment, a sky box (visible sky and cloud cover), doors and windows, ladders to terrain development, and scenario creation with the placement of terrorists or AI enemy units.

The Unreal Editor is the heart of the creation process for new Raven Shield environments and is used for the entire process. It has primitive shape tools, stair tools, and all other tools required for building an environment.

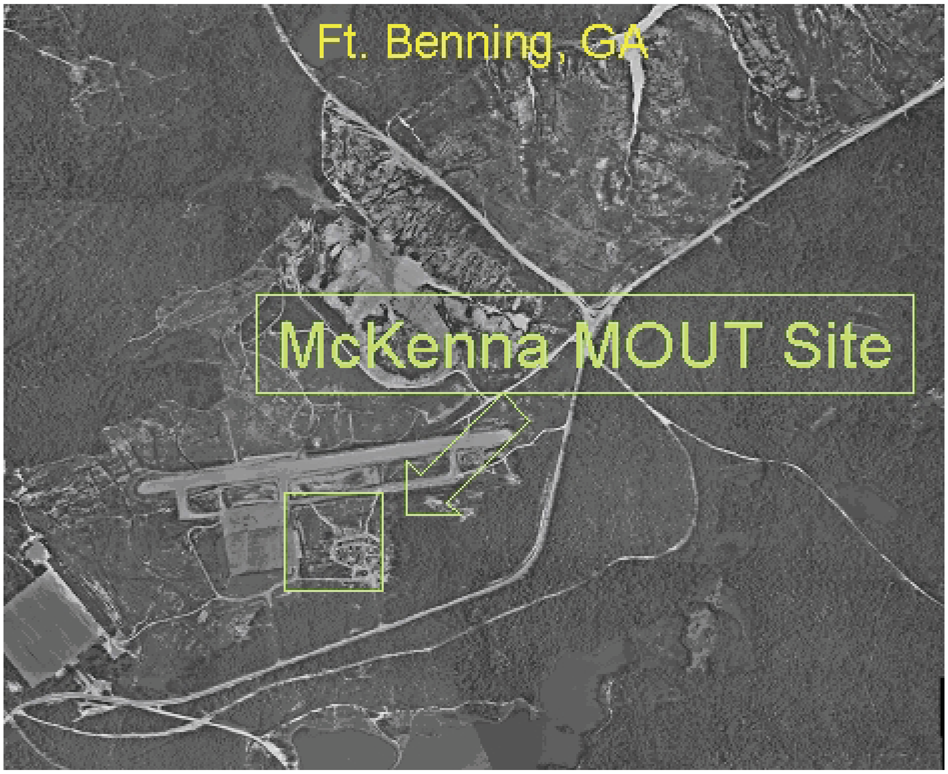

Figure 2. Satellite photograph of the McKenna MOUT site at Fort Benning.

Figure 3. Aerial view of the McKenna MOUT site.

4.1 Creating the 3-D Space in Unreal Editor

The first step in the creation of the virtual space was to define the building 3-D subtraction space (or the entire "box" in which the environment is built). This was approximately 400 meters on the X, Y, and Z axes (see figure 4). It was determined through trial and error that this was the largest environment that could be built to avoid visual clipping and would finalize to be a square 220- by 220-meter terrain. This square was then oriented to be a diamond shape, where the top of the diamond would be north. This was to maximize traversable space north-south and east-west to approximately 311 meters.

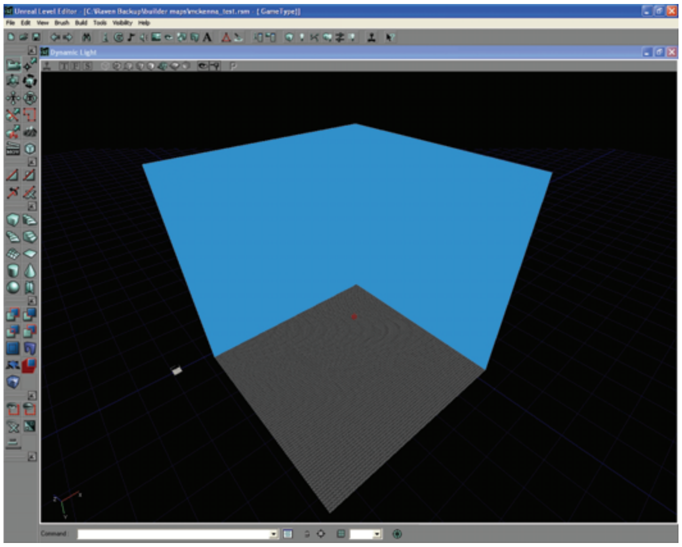

Figure 4. Subtraction space for the virtual McKenna MOUT site.

4.2 Creating the Skybox and Terrain Model

The next step was to build a sky box. Since it already resided in Raven Shield, the creation of the sky box was limited to building the functionality that would contain a pre-built sky box. This was a blue sky with some light clouds. To create the terrain model, elevation data were cut from an OpenFlight model of McKenna. This elevation was then converted into a gray-scale height map for importation as a texture into the *McKenna_SM.utx* file, the texture file for the environment. This gray-scale height map would then be converted into a 3-D terrain for the ground at the McKenna MOUT site. Figure 5 shows the gray-scale height map created for use in the Unreal Editor for terrain elevation. Figure 6 shows the completed terrain model in the 3-D space.

Figure 5. Gray scale height map.

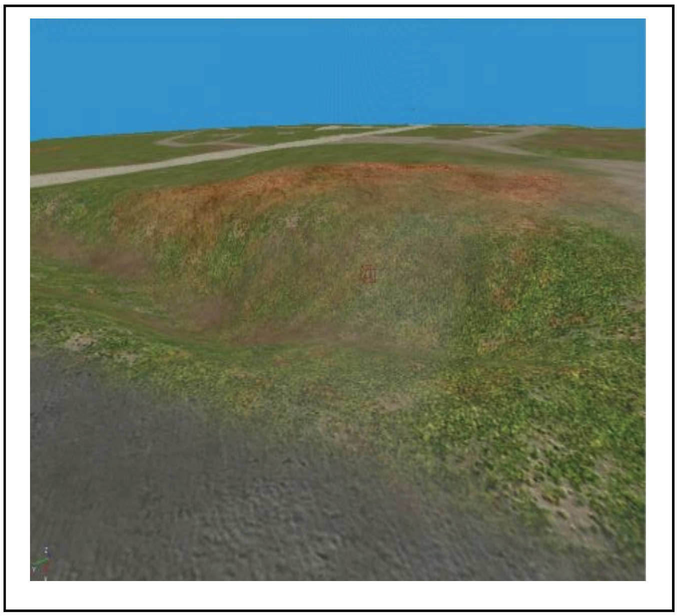

Figure 6. Terrain model in 3-D space.

4.3 Creating New Textures

We created textures for buildings and some custom ground cover textures by exporting current Raven Shield textures to PhotoShop[2]. These textures were then re-colored and brightened or darkened to approximate the textures on the actual buildings at the McKenna MOUT site. Textures that are created or borrowed from another texture package are usually placed into a new

[2]PhotoShop is a registered trademark of Adobe Systems, Inc.

texture package. These new textures were then re-imported back into the *McKenna_SM.utx* package for building creation and terrain painting. We created a sample of these textures that were custom made for the game by adjusting color and brightness values in Adobe PhotoShop. These textures were then re-imported back into a usable texture format for the Unreal Editor. Figure 7 illustrates a few of the textures used in the environment, particularly those used for ground cover and buildings.

Figure 7. Sample of textures created for the virtual McKenna MOUT site.

4.4 Terrain Painted With Features

The 3-D terrain model was painted with a paint tool. This process allowed the selection of several terrain layers to be used and "air brushed" onto the model. Aerial and ground photographs and McKenna design drawings were used to ensure the accuracy of terrain texture details. This was primarily to ensure that roads and paths were correctly emplaced. Corners of buildings, spaces between buildings, and other dimensions were also used to appropriately space the road and path features onto the terrain. The OpenFlight terrain model, which included road and path images, was converted into a static mesh and overlaid into the terrain for accuracy. Figure 8 shows the terrain after roads, paths, and vegetation were painted.

Figure 8. Roads, paths, dirt, and vegetation painted on terrain.

4.4.1 Paint Terrain, Place Buildings, Place Vegetation

Terrain was painted, based on aerial and ground video and photographs. The primary area of concern was that the trails and paths be accurately re-created for realism.

4.5 Creating Extra Objects (creating a static mesh package)

Objects that are considered simple and non-interactive can be built as static meshes in the Unreal Editor. These objects require less graphic processing and do not have any game-related attributes assigned to them other than brightness and shadowing effects for the most part. Examples of static meshes in Raven Shield are park benches, trash cans, and furniture. Static meshes that are created or borrowed from another static mesh package are placed into a static mesh package. This package was named *McKenna_SM.usx*. Figure 9 demonstrates two created static meshes: a fire hydrant and a "jersey wall" barrier. Many other objects were created, including sewer system access points, phone booths, and a stone sculpture.

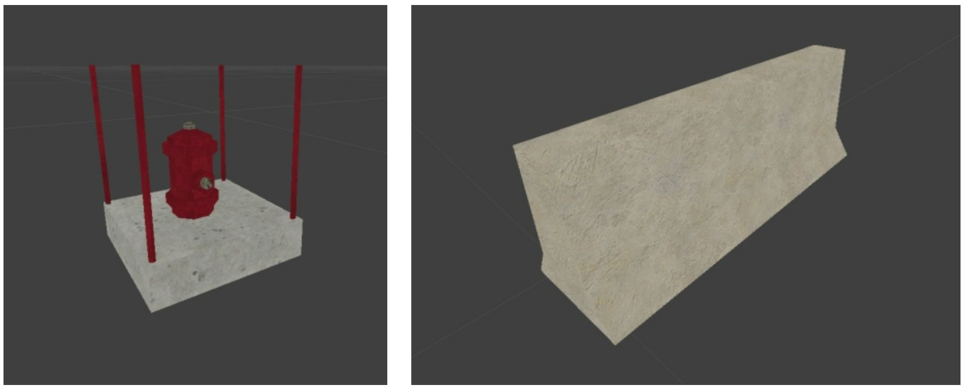

Figure 9. Static mesh objects created for the virtual McKenna MOUT site.

Aerial photographs of McKenna were used as well as a large number of photographs that were taken of McKenna before this project.

We viewed several aerial movies of McKenna to get a perspective of the entire area being built.

4.6 Creating Buildings

Buildings were created from scratch to scale for the Raven Shield environment in the Unreal Editor. Several attempts to import OpenFlight models of buildings were made but failed. These attempts failed because of errors with the geometry of the buildings and irregular normals (the direction texture's face on a surface). The buildings were built one at a time in separate "build environments". These were stand-alone environments that were created for the purpose of creating each building individually and for the clean condition of the sky box and terrain environment. Only when a building was completed was it allowed to be placed into the McKenna MOUT environment.

Note: Unreal units are the basic measure of space in the editor. One Unreal unit is equal to about 1 centimeter.

Building dimensions were provided by the Fort Benning field element. Dimensions were held as closely as possible to the real ones, but doorway dimensions required larger dimensions to accommodate the Raven Shield game engine. The Raven Shield simulation had minimum requirements for doorway and hallway dimensions. It was conceivable that players' characters could become "stuck" in the smaller doorway dimensions, so the design specifications for Raven Shield were used.

Buildings were created from primitive shapes to form floors and ceilings first. Interior and exterior walls were then created. Stairs were created after that, if necessary, for that building. Rooftop building ledges were included if a rooftop access was available in that building. Following that, subtraction boxes or "cut-outs" were created for all doorways, windows, and even mouse holes. These were all checked to be sure every building was created as accurately as possible. Figure 10 depicts the early stages of building development, specifically building B2 as a wire frame.

The next phase of building development was to texture the surfaces of the building appropriately. Floors, ceilings, interior walls, exterior walls, and rooftops with flat surfaces or peaks were textured. Texturing is not limited to just selecting a texture. Its orientation, size, horizontal and vertical positioning must all be taken into account for a realistic looking building. Figure 11 shows the texturing process for a partially completed building B2.

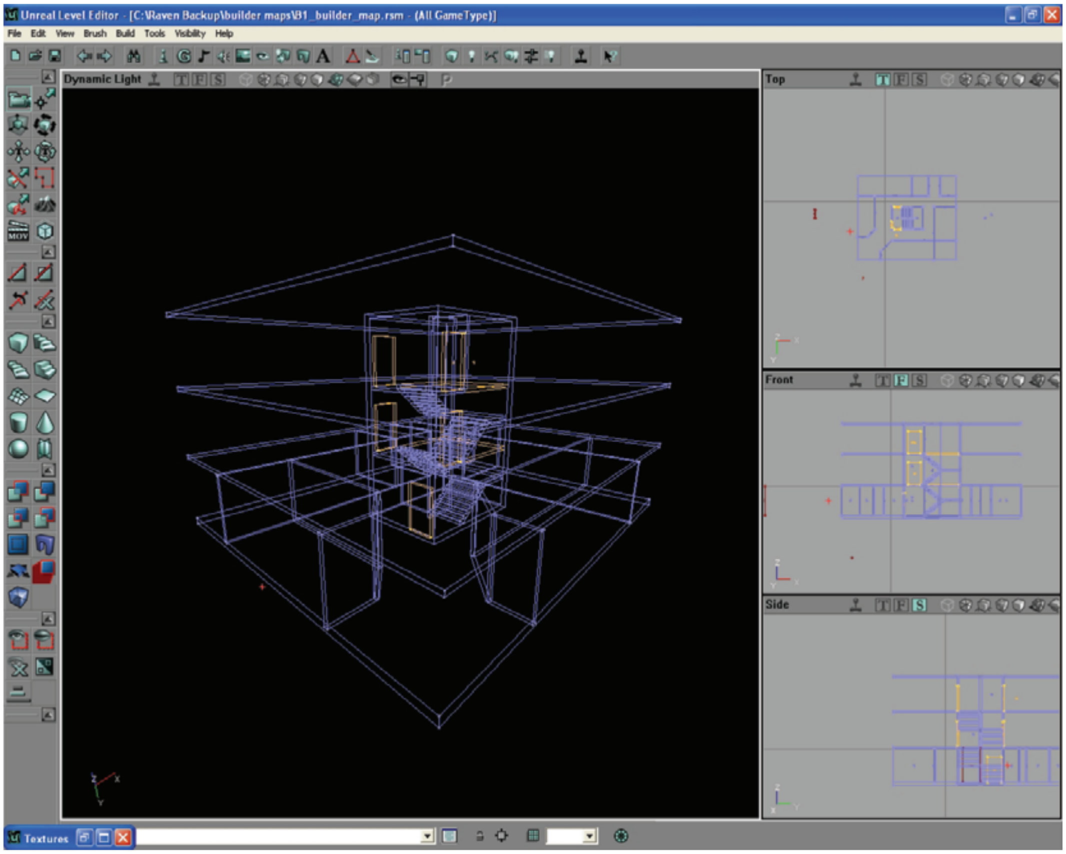

Figure 10. Wire frame of building B2.

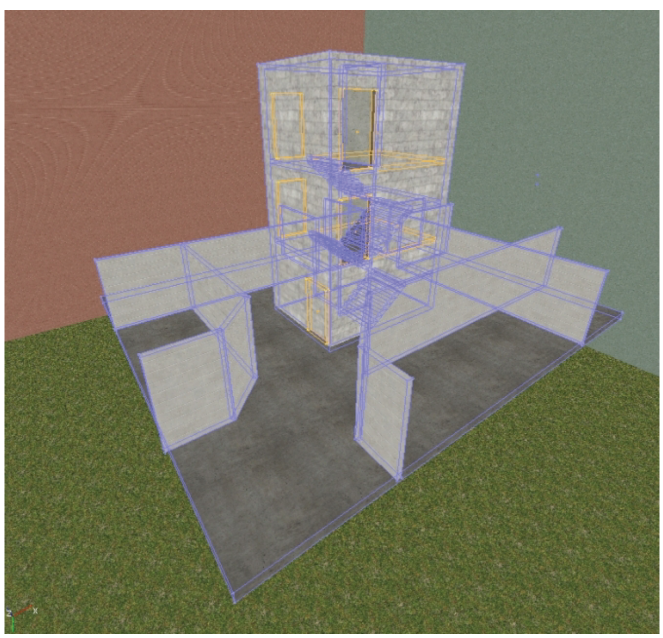

Figure 11. Texturing of building B2.

After the building was completed, it was then imported into the McKenna MOUT environment and placed correctly on the terrain (see figure 12). The building, however, was not complete at this point. Several other features had to be put into each building. These features included path nodes, portals, zone information, and doors.

Figure 12. Building B2 placed on the McKenna MOUT terrain.

They are described briefly in the following:

- Path nodes are placed into every building (and across open terrain) so that friendly and enemy AI units can follow prescribed paths or re-join a team leader after being ordered to do so. They simply let AI do path planning.
- Portal placement is used to divide the rooms into spaces that can be ignored by the graphics engine when they are not in the player's line of sight. They ease the game's processing requirements.
- Zone information is placed into each room on the interior to give it its own lighting characteristics. Brightness, color, and hue can all be altered to give each room a different look. Most rooms were darkened somewhat so that they would be contrasted to the exterior brightness level.
- Interactive doors were placed in doorways. These allowed the action of opening and closing doors when appropriate in the environment.

4.7 All the Extras

After all buildings were created and placed into the environment, other extras had to be included in order for the environment to run efficiently and correctly. These features included the following:

- Zone information. This was used for the exterior lighting level. This gave an overall ambient lighting level but does not produce shadows.
- Sun lighting. A sunlit object was created and placed in the environment to throw more intense "sunlight" onto surfaces and to create shadows. The attributes of angle, brightness, hue, and color can all be adjusted for sunlight.
- Path nodes (see above).
- Portals (see above).
- Player insertion points. These are the spawn points for single-player (player against computer AI enemy) and multi-player (multiple players in team-against-team or against computer enemy AI).
- Lights (static meshes for light fixtures). Static meshes.
- Furniture. Static meshes.
- Assorted interior objects. Include fire extinguishers, chemical canisters, etc. Static meshes.
- Assorted exterior objects. Automobiles, phone booths, jersey walls, sewer accesses, cemetery headstones, fences, shipping containers, etc. Static meshes.
- Vegetation. All trees, shrubs, and grasses. Static meshes.
- Enemy AI units (discussed further in next section).

4.8 Enemy Artificial Intelligence Units

The enemy AI units were greatly customized before final placement in the McKenna MOUT site. Many characteristics of the AI units can be manipulated, such as clothing or uniform (gas mask or not), language spoken, weapon configuration (including assault rifle, sub-machine gun, pistol, and grenade type).

The AI "intelligence" can be altered in the template browser to include such attributes as

- Skills (set from 0% to 100%); assault, demolitions, electronics, sniper, stealth, self control, leadership, observation.
- Personality (a mix of each, all totaling 100%); coward, desk jockey, normal, hardended, suicide bomber, sniper.

- Weapon (type of rifle, machine gun or pistol).
- Grenade (type, fragmentation, smoke, tear gas, flash bang).
- Flashlight.
- Attachment (gas mask, glasses, or sunglasses).

AI can also have paths to follow, triggers to respond to, and groups of other enemy AI that they "communicate" with and receive alerts from.

In all, quite a few attributes can be changed to create a custom level of difficulty for any scenario. A screen shot of an enemy AI unit is shown in figure 13.

Figure 13. Enemy AI unit placed in the VMMS.

4.9 The Final Product

The final working map of the McKenna MOUT site was then completed and tested. Several bugs were found and the map was rebuilt several times. (Note: re-build is a term for re-compiling the map qualities, not re-building it from scratch.) Figure 14 shows a top view of the product with all vegetation. Figure 15 shows an aerial view.

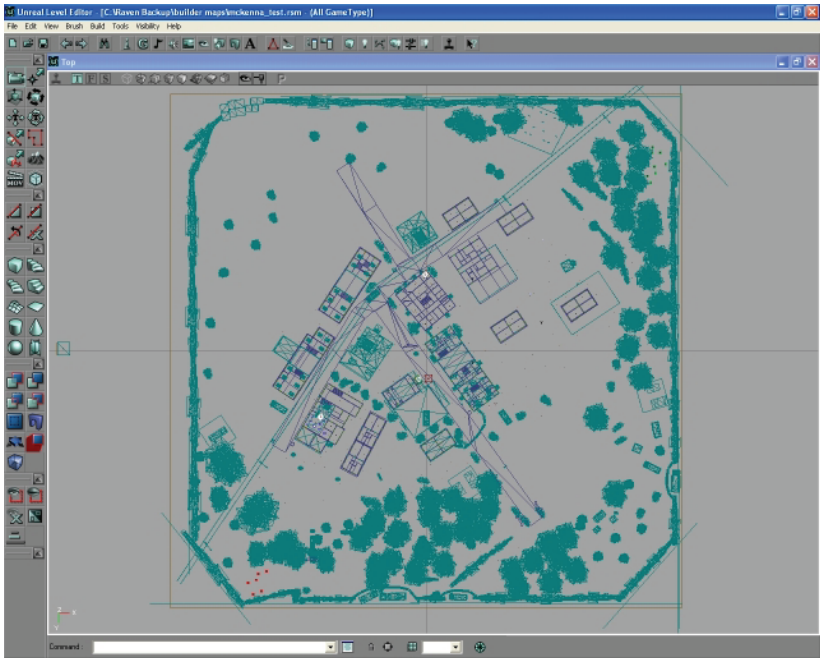

Figure 14. Top view of the completed wire frame at the VMMS.

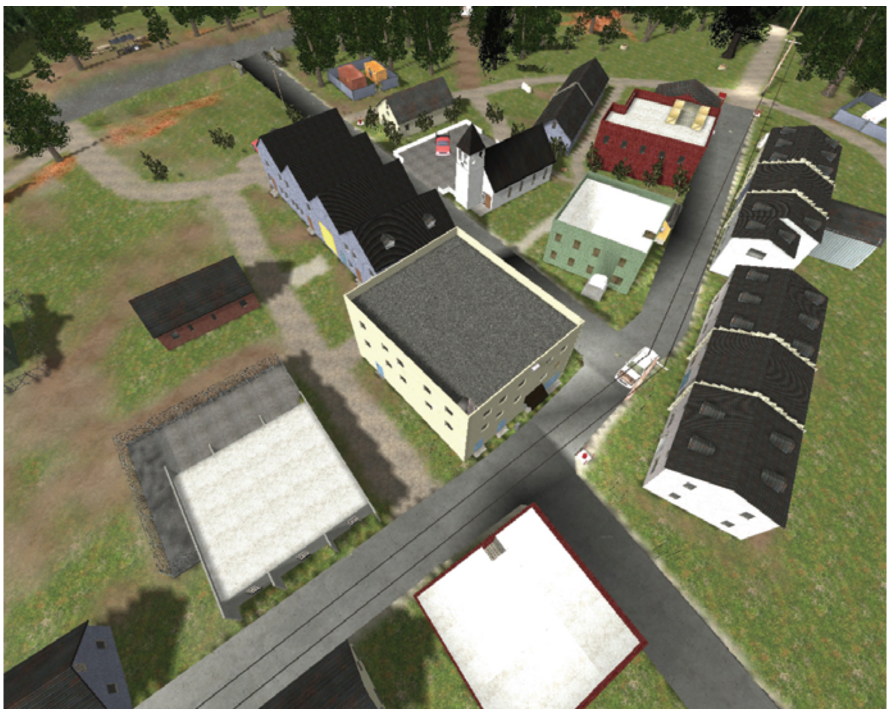

Figure 15. Aerial view of the completed VMMS.

4.9.1 Benefits of Simulation and Gaming Technology

- Rapid generation of Soldier-in-the-loop data to
    - Feed models of Soldier performance.

    - Fill data voids.
    - Provide preliminary design guidance.
    - Examine various tactics, techniques, and procedures.
    - Examine potential workload bottlenecks in a C4I system.
- No prototypes required.
- Run multiple iterations of a tactical scenario in a laboratory, low-cost environment.

4.9.2 First Use

4.9.2.1 Situational Awareness Questionnaire Validation Study

Three specific mission vignettes were built for the ARL field element. These missions were the first instances of the use of Raven Shield to collect human performance data. An entire package exists that can be put into Raven Shield via a software “installer”. This installer automatically places the entire contents into the appropriate directories to reduce work associated with using this add-on package. This package includes three experimental vignettes or scenarios and one training scenario to help users become familiar with the environment.

- Completed and ready for use with three vignettes July 2003.
- As many as eight Soldiers in multi-player mode against computer AI threat forces.
- Civilians on the battlefield included in some vignettes.

The three vignettes were detailed by the Fort Benning personnel. From these descriptions, enemy AI, dead civilians, chemical canisters, and triggers that notify the player of sensor hits for chemical contamination are triggered by player proximity to these triggers. The training scenario includes a chemical cloud and several dead animals to let the player know that a chemical threat is in the area. A real photograph looking south down the main street at the McKenna MOUT site is shown in figure 16. A screen shot from the VMMS is shown in figure 17 for comparison. An additional overhead view is shown in figure 18.

Figure 16. McKenna MOUT site, actual photograph.

Figure 17. McKenna MOUT site, virtual screen shot.

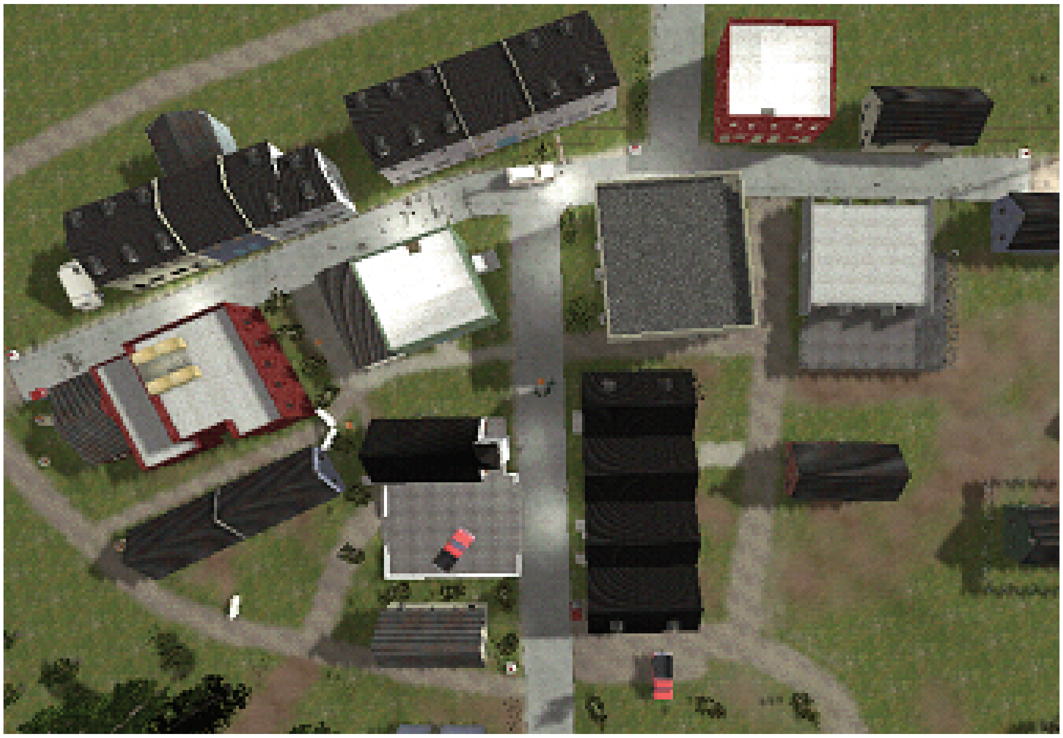

Figure 18. Overhead view of the virtual McKenna MOUT site.

5. Conclusions

This was the first instance at ARL that allowed the use of human performance data collection in a VMMS. The future of human performance data collection has wide application to many areas of Soldier cognition and mission performance parameters. Several areas of Soldier cognitive performance may be easily represented by allowing interaction in virtual environments: SA, mission planning, navigation, advanced sensors, and team interaction.

A number of areas require improvement in the data collection. These improvements include

- Data collection ability for movement and all other actions.
- Mission record capability for playback.
- Open editor and scripting capability that allow modifications such as new weapon systems, optics, sensors, and other data collection schemes.

An attempt to validate Soldier performance in a virtual environment such as this will be attempted in the future to further this work.

6. McKenna MOUT Environment Available for Public Release

A self-installing executable file was created that will allow e-mail, CD-ROM[3], memory stick transport of this map environment. The environment was made available for public release via ARL Form 1 in April 2005.

For a copy of the environment, call or e-mail the authors:

- David Scribner, dscribner@arl.army.mil, (410) 278-5983, or
- Patrick Wiley, pwiley@arl.army.mil, (410 278-5994.

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